

囊谦盆地贡觉组砂岩岩石学特征与物源分析

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摘要:在详细观察描述砂岩宏观特征的基础上,对贡觉组碎屑岩骨架组分、常量元素变化规律进行分析,研究了该地区砂岩的岩石学和物源特征,并指出囊谦盆地的沉积序列由下而上($E_g^1 \sim E_g^5$)具砂岩成分成熟度由差变好再变差的趋势。物源演变趋势分析揭示,沉积早期盆地北、西北部的构造运动强烈,为第二段(E_g^2)沉积时期提供成熟度很低的碎屑物质,而第一段(E_g^1)至第二段(E_g^2)沉积时期长石含量降低而岩屑含量递增,构造强度逐渐增强,冲积扇-河流相处于发育阶段,第三段(E_g^3)层序发育时,构造运动逐渐减弱,长石含量增高而岩屑含量逐渐降低,但盆地西北、北部继续遭受强烈剥蚀,东部和南部则下降接受沉积,并伴有岩浆活动,湖泊层序发育达到顶峰,第四段(E_g^4)和第五段(E_g^5)层序沉积时转而接受过渡型再旋回造山带区,长石含量先增加后降低而岩屑含量先降低后增加。

关键词:囊谦盆地,砂岩,岩石学特征,物源演变

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Petrological characteristics and provenance analysis of sandstones of Gonjo Formation in Nangqen basin

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Abstract: Nangqen basin is a typical representative of the medium-mini-type Paleogene basins controlled by local NNW-trending faults distributed along Jinsha River-Red River belt on the northeastern margin of Qinghai-Tibet plateau. Gonjo Formation is perfectly developed and dominated by a set of thick-bedded, purplish red, red terrigenous clastic rock formation containing gypsum rock in association with large-scale high potassium rocks in Nangqen basin. Combined with results of field geological investigation and analysis and determination of samples as well as quantitative studies of the sandstone framework detrital composition of the Paleogene strata, the authors systematically analyzed petrologic characteristics of the sandstones of the Gonjo Formation in Nangqen basin in the framework of the basin evolution. According to the analysis of geochemical features of sandstones of the Gonjo Formation, the characteristics of paleoclimate, paleoenvironment and provenance in the study area were revealed. For sandstones in different strata of Gonjo Formation, systemic sampling and determination were conducted, the detrital composition of sandstone was observed under a microscope, and the sandstone framework detrital composition was calculated and analyzed using the line-count method. The quantitative data of the clastic constituents not only constitute the nomenclature foundation of sandstones but also provide an important basis for understanding the nature of the sedimentary basin and estimating the provenance region. Meanwhile, the data

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processing methods included the genetic classification of the clastic constituents and the triangular graphical analysis. According to the theoretical analysis and the results of Dickinson W.R., the authors analyzed and discussed the relationship between the provenance and the plate tectonics of clastic rocks of Gonjo Formation. The results indicate that the sandstones of Gonjo Formation belong to recycling orogenic belt area, and only the samples of Eg^2 came from polycyclic orogenic belt area and cratonic interior. From the viewpoint of geological features as well as the position of composition plots, it is considered that the provenance evolution began from stable cratonic interior to lithic recycling orogenic belt and polycyclic orogenic belt area. The trend of the composition maturity in the sedimentary successions from Eg^1 to Eg^5 was low-high-low. Provenance evolution analysis shows that the tectonic movement was very intense in the northern and northwest parts of the basin during the early deposition, which provided the period of the 2nd member (Eg^2) with low maturity detritus. From Eg^1 sequence to Eg^2 sequence, with the increasing strength of the tectonic movement, the content of feldspar had a decreasing tendency while that of lithoclast had an increasing tendency. And the alluvia fans, i. e., the fluvial facies were at the primary stage of development. In terms of Eg^3 , the tectonic movement began to taper off, the content of feldspar increased, and lithoclast decreased gradually, which however brought about the end of lake sequence development, with strong uplifting and erosion in northwest and north parts of the basin, the deposition heaped up in the depressions, and the existence of igneous activities in east and south parts of the basin. As for Eg^4 and Eg^5 , the provenance changed into a transitional recycled orogen, and the content of feldspar presented an increase-decrease tendency, while the tendency of lithoclast content was on the contrary. Through an analysis of the changes of the detrital composition of sandstone, Nangqen basin underwent two stages of tectonic evolution in which the early stage belonged to the reverse-compression and the late stage to strike slipping-compressional deformation. The evolution trend of tectonic evolution combined with the detrital composition changes in each sequence was studied. An analysis of the major elements of sandstones indicates that felsic rocks were dominant in the provenance, accompanied by mafic rocks. Varying tendency of chemical index of weathering (CIW) is similar to that of the chemical index of alteration (CIA) from Eg^1 to Eg^4 , and this index is used to reflect the weathering intensity from weak to strong and to weak again. Variation of the index of compositional variability indicates the circle of lower compositional maturity-higher compositional maturity-lower compositional maturity from Eg^1 to Eg^4 in the section, suggesting that geological conditions of the provenance region had significant differences. The paleo-climatic environment changed from warm-moisture through drought-hot to moisture in upward succession during the depositional period. The provenance of the sediments of Gonjo Formation was based on felsic rocks, with the provenance of Eg^3 sequence having a small quantity of mafic rocks, probably due to the movement of shear-strike slip faulting that resulted in gradual extension to the upper mantle and induced partial melting of basement materials which erupted or intruded into Eg^3 sequence.

Key words: Nangqen; sandstone; petrological characteristics; provenance evolution

中国西南部青藏东北缘横断山-金沙江-红河一带发育众多的早第三纪盆地,因其具复杂的构造背景、沉积地层、地貌景观以及丰富的矿产资源而备受中外地学界瞩目(潘桂棠等,1990;Turner *et al.*, 1993;Molnar *et al.*, 1993;Liu *et al.*, 1996;施雅风等,1998;孙红烈,1998;顾延生等,2000;周江羽等,2007)。囊谦盆地是横断山北段走滑拉分盆地的典型代表,接受沉积较晚,发育较为齐全,侵入该区岩浆岩的 $^{40}\text{Ar}/^{39}\text{Ar}$ 杨大雄等,1988;朱丽等,

2006) K-Ar(邓万明等,1999)定年结果以及孢粉化石、介形类化石时代(卫民,1985)均表明沉积物主要形成于晚始新世—早渐新世。在沉积学方面,20世纪90年代以来对该区充填的沉积形式、构造格架(周江羽等,2003;张克信等,2007;姜勇彪等,2009)岩相古地理、古水流和沉积体系(Horton *et al.*, 2000;王世锋等,2001;周江羽等,2002;Spurlin *et al.*, 2005)等进行了有益的探索,但对该区沉积岩层的物质来源问题还存在一些认识上的分

歧。王世锋等(2001)认为物源单一,主要物源来自于盆地东南缘;周江羽等(2002)依据原生沉积构造认为该区早期物源主要来自于西部,晚期则来自于东部。在前人基础之上,应用碎屑矿物的定量分析和元素地球化学方法,对研究区的砂岩碎屑矿物成分、常量元素进行分析,揭示盆地沉积物的物源特征及其构造背景,有助于澄清源区和沉积区的关系,沉积物搬运的路径、距离和物源区的地理位置。

1 地层特征

在区域上,囊谦盆地贡觉组红层形成于早第三纪(卫民,1995;邓万明等,2001;朱丽等,2006;Spurlin *et al.*,2005),不整合于古生代、中生代地层之上,与周围石炭系、三叠系灰色岩层地貌特征差别显著。根据剖面控制,结合路线地质,在盆地演化的格架内,系统分析了囊谦盆地贡觉组沉积特征及沉积环境等方面的特征(杜后发等,2011)。按沉积充填序列、岩性特征及岩石组合,可将贡觉组由下而上划分为以下5个层段:

第1段(E_g^1)为深水湖泊相沉积,仅出露于盆地中部西侧都日哇地区一带,下部为灰白色粉砂岩、泥灰岩和泥质粉砂岩夹薄层泥岩,中部土灰色、灰白色粉砂质泥岩与中薄层灰岩构成12个旋回韵律层,夹有黑色油页岩,上部为紫红色泥岩夹粉砂质泥岩。

第2段(E_g^2)为近源、快速堆积,以冲积扇-河流相沉积为主,盆地北部广泛出露,由灰色、灰绿色和紫红色巨厚层状砾岩、砂砾岩及少量的粉砂岩和泥岩构成,表现出南薄北厚、南细北粗的特点。

第3段(E_g^3)为一套封闭的盐湖相沉积,分布广泛,沉积厚度显示南北厚中部薄的特点,平面分布常有明显的分带性,垂向上随着盐度的增加,蒸发岩矿物以相同型式周期出现,呈现紫红色粉砂质泥岩-石膏、硬石膏、灰岩和少量的碎屑物构成的混积岩层。

第4段(E_g^4)出露于盆地东南、西侧和中部东侧,沉积厚度变化较大,盆地东侧沉积最厚,下部为一套河流相为主的紫红色-红色砂岩、粉砂质泥岩和泥岩,上部为以一套冲积扇相为主的红色砾岩、砂砾岩。

第5段(E_g^5)为一套以冲积扇-河流-三角洲相为主的红色巨厚层砾岩、砂砾岩,沉积厚度大于2300 m,垂向上见薄层状砾岩与砂岩互层,或砾岩未见顶。

2 样品处理和分析方法

针对贡觉组地层不同层段取样51块,选取砂岩进行碎屑成分定量分析。对薄片图像中的抽样点选用线计法统计,计点的抽样工具是目镜刻度尺。利用物台微尺标定偏光显微镜目镜刻度尺,然后对显微镜视域内的图像进行测量和分析。线计法是人工使用机械台等间距地移动薄片,测定纵丝或横丝通过的全部碎屑颗粒的粒径并计数。该方法既能满足砂岩测试的精度要求,又有很高的工作效率。对本区11块砂岩薄片的碎屑矿物含量进行统计,每片统计350粒,将外源碳酸盐碎屑、变质岩屑归入沉积和变质沉积岩岩屑(L_s),半深成、变质火山隐晶岩屑归入火山岩岩屑(L_v)。

3 分析结果

3.1 碎屑岩骨架颗粒成分

碎屑岩类成分反映了物源区性质。由于搬运过程中稳定组分受到破坏,碎屑岩类成分并不总是与源区岩性完全一致,尤其在潮湿环境中化学风化作用更为强烈时,因此,详细、准确的砂岩碎屑成分定量分析可为物源区分析和沉积盆地性质分析提供重要依据,其可信度优于地球化学分析资料。

囊谦盆地贡觉组砂岩碎屑矿物成分统计数据见表1。按照囊谦盆地沉积充填序列,自下而上各组砂岩碎屑矿物组分特征简述如下:

E_g^1 :岩石呈土黄色,岩性为长石岩屑砂岩,石英碎屑以单晶石英为主, Q_m/Q 为0.92(Q 为总石英质颗粒, Q_m 为单晶石英颗粒),以次圆状为主,其次有少量的次棱角状,具有熔蚀边、炸裂纹,无波状消光等特征,表明砂岩中的单晶石英主要来自火山岩。多晶石英在砂岩样品中较少, Q_p/Q 为0.05(Q_p 为多晶石英质颗粒)。岩屑含量占42%,以沉积岩屑为主, L_s/L 为0.93(L 为总非稳定隐晶岩屑),主要由泥岩、粘土岩、少量的碳酸盐岩组成;火山岩岩屑以火山霏细岩岩屑为主。长石含量占18%,以酸性斜长石为主,聚片双晶纹较细,部分已绢云母化;极少量的为钾长石, K/F 为0.08(K 为钾长石颗粒, F 为总长石颗粒)。碎屑颗粒边缘粘土矿物吸附 Fe^{3+} ,呈褐红色。

E_g^2 :岩石呈红色、紫红色,岩性为长石石英砂

表 1 囊谦盆地贡觉组砂岩碎屑矿物成分统计数据(据 Dickinson, 1983)

Table 1 Statistics of detrital mineral composition of sandstones in Gonjo Formation of Nangqen basin (after Dickinson, 1983)

| 序号 | 样号 | 层位 | 岩性 | Q 类 ($Q_m + Q_p$) | | | F 类 (Pl+K) | | | L 类 ($L_v + L_s + L_t + L$) | | | |
|----|-------|-----------|--------|---------------------|-------|----|------------|---|----|-------------------------------|-------|-------|----|
| | | | | Q_m | Q_p | Q | Pl | K | F | L_v | L_s | L_t | L |
| 1 | ys027 | E_g^1 | 长石岩屑砂岩 | 37 | 2 | 39 | 17 | 1 | 18 | 3 | 39 | 44 | 42 |
| 2 | ys043 | E_g^2 下 | 长石石英砂岩 | 85 | 5 | 90 | 5 | 2 | 6 | 2 | 2 | 9 | 4 |
| 3 | ys040 | E_g^2 上 | 岩屑砂岩 | 30 | 5 | 34 | 11 | 2 | 12 | 9 | 45 | 58 | 53 |
| 4 | ys034 | E_g^3 | 长石岩屑砂岩 | 36 | 4 | 40 | 14 | 3 | 18 | 11 | 31 | 46 | 43 |
| 5 | ys022 | E_g^3 | 长石岩屑砂岩 | 61 | 4 | 65 | 16 | 1 | 17 | 4 | 14 | 22 | 18 |
| 6 | ys015 | E_g^4 下 | 长石岩屑砂岩 | 55 | 3 | 58 | 18 | 2 | 20 | 3 | 19 | 25 | 22 |
| 7 | ys018 | E_g^4 中 | 岩屑长石砂岩 | 55 | 5 | 60 | 22 | 5 | 27 | 3 | 11 | 19 | 14 |
| 8 | ys010 | E_g^4 | 岩屑长石砂岩 | 43 | 5 | 48 | 27 | 1 | 28 | 5 | 19 | 29 | 24 |
| 9 | ys009 | E_g^4 | 岩屑长石砂岩 | 45 | 8 | 52 | 32 | 2 | 34 | 4 | 10 | 22 | 14 |
| 10 | ys026 | E_g^5 | 岩屑长石砂岩 | 50 | 4 | 55 | 18 | 8 | 26 | 5 | 15 | 24 | 20 |
| 11 | ys014 | E_g^5 | 岩屑长石砂岩 | 55 | 6 | 61 | 19 | 2 | 20 | 4 | 15 | 25 | 19 |

注 碎屑参数: Q—总石英质颗粒; Q_m —单晶石英颗粒; Q_p —多晶石英质岩屑(燧石等); P—总长石颗粒; Pl—斜长石颗粒; K—钾长石颗粒; L—总非稳定隐晶岩屑; L_v —火山的、半深成、变质火山隐晶岩屑; L_s —沉积和变质沉积岩屑; L_t —总隐晶岩屑颗粒 ($L + Q_p$)。

岩、岩屑砂岩。贡觉组 E_g^2 下段砂岩碎屑主要为石英碎屑, 石英碎屑约占 90%, 单晶石英含量较高 85%, Q_m/Q 为 0.94, 其形态以次圆状、圆状为主, 少量的次棱角状, 部分具炸裂纹、波状消光、石英自生加大边、颗粒较为圆滑且有方解石包体等特征, 表明砂岩中的单晶石英来自酸性火山岩、沉积岩。多晶石英为燧石、梳状石英, Q_p/Q 为 0.06。长石碎屑为酸性斜长石、微斜长石, 斜长石表面绢云母化强烈而微斜长石表面干净, 斜长石含量高于钾长石含量, K/F 为 0.28。 E_g^2 上段砂岩碎屑主要为岩屑碎屑, 以脉石英岩屑、变质石英岩屑、千枚岩岩屑、硅质石英岩屑和碳酸盐岩岩屑为主, 其次为火山霏细岩岩屑和花岗岩岩屑, 其含量约占 53%, L_v/L 为 0.16, L_s/L 为 0.84。该层段砂岩石英含量约占 34%, 以单晶石英为主, Q_m/Q 为 0.87。长石碎屑含量为 13%, 酸性斜长石含量高于钾长石含量, K/F 为 0.13。

E_g^3 岩石呈紫红色, 岩性为长石岩屑砂岩。石英碎屑含量占 40%~65%, 平均含量为 52.5%, 以单晶石英碎屑为主, 多为次圆状, 具炸裂纹, 无波状消光, 缺乏矿物包体等特征, Q_m/Q 为 0.91~0.93, 表明单晶石英主要来自酸性火山岩。长石碎屑为酸性斜长石, 聚片双晶单体较细, 多为次圆状, 颗粒边缘被方解石交代, 其含量占 16%~18%, Pl/F 为 0.80~0.94 (Pl 为斜长石颗粒)。岩石碎屑为花岗岩岩屑、火山霏细岩岩屑、云母石英片岩岩屑、硅质岩屑, 其含量为 18%~43%, L_s/L 为 0.73~0.79, L_v/L 为 0.21~0.27。

E_g^4 岩石呈红色, 岩性为岩屑长石砂岩。石英

碎屑含量 48%~60%, 平均含量为 54%, 以单晶石英碎屑为主, 石英颗粒边缘被溶蚀, 个别见有包裹体和石英次生加大边等特征, 多为次棱角状、棱角状, Q_m/Q 为 0.85~0.94。长石碎屑以酸性斜长石为主, 聚片双晶单体较细, 次棱角状, 其含量占 20%~34%, 平均含量为 27%。岩屑碎屑有云母石英片岩岩屑、硅质岩屑、火山霏细岩岩屑, 以次圆状为主, 其次是次棱角状, 其含量占 14%~24%, 平均含量为 18.5%, L_s/L 为 0.74~0.86, L_v/L 为 0.14~0.21。

E_g^5 岩石呈暗紫红色, 岩性为岩屑长石砂岩。石英碎屑含量占 55%~61%, 平均含量为 58%, 以单晶石英碎屑为主, 见有石英颗粒边缘被方解石交代、石英自生加大边等现象, 以次棱角状-次圆状为主, 其次少量的为圆状, Q_m/Q 为 0.90~0.92。长石碎屑以酸性斜长石为主, 聚片双晶发育, 轻微的绢云母蚀变, 偶见具有格子双晶的微斜长石, 以次圆状为主, Pl/F 为 0.70~0.92。岩屑碎屑有火山霏细岩岩屑、粉砂岩岩屑、硅质岩屑等, 以次圆状为主, 其次是次棱角状, 其含量占 19%~20%, L_s/L 为 0.75~0.79, L_v/L 为 0.21~0.25。

3.2 砂岩常量元素特征

Taylor 和 McLennan (1985) 提出的澳大利亚后太古宙页岩 (PAAS) 被公认为上地壳的平均化学成分, 可以作为一个地球化学标准来分析样品的地球化学特征。贡觉组砂岩样品的常量元素分析数据见表 2。

通过与大陆上地壳平均化学成分对比, 可知囊谦盆地贡觉组碎屑岩的 SiO_2 含量变化范围较大 (50.03%~79.72%, 平均为 63.72%), 略高于

PAAS,说明砂岩中石英或富含 SiO₂ 的矿物(如长石类)含量略偏高。贫 Al₂O₃(4.59%~10.73%,平均为 6.65%),可能与砂岩中长石类、云母类和粘土矿物等富铝矿物较少有关;贫 TiO₂(<0.41%)、P₂O₅(<0.15%)、MnO(<0.09%),K₂O/Na₂O(一般为 0.88%~7.24%,平均为 3.15%)偏高,TFe+MgO(1.40%~5.46%,平均为 2.64%)普遍偏低,说明贡觉组碎屑岩源区为长英质岩石。另外,样品中 CaO 含量普遍高于上地壳的平均丰度 1.29%,是由于填隙物中有方解石胶结物的缘故。

4 讨论

4.1 源区大地构造性质及岩石类型判别

砂岩是陆源碎屑岩的主要岩石类型,其碎屑物质主要来源于母岩机械破碎的产物。陆源碎屑岩在沉积建造中占据绝对优势,砂岩碎屑组分是判断物源区母岩类型的有力证据。应用 Dickinson 和 Suczek(1979)、Dickinson(1983)先后提出的两套碎屑成分物源区分析定量图解,对贡觉组(Eg¹~Eg⁵)砂岩样品中的石英、长石和岩屑含量进行定量分析统

计,并以 QFL、Q_mFL_t 为端员成分进行三角图投点(图 1),在此基础上对囊谦古近纪盆地贡觉组碎屑岩进行了物源与板块构造关系的分析和探讨。

分析结果表明,砂岩投点落入(混合)再旋回造山带物源区,Eg² 样品落入过渡再旋回造山带物源区和克拉通内部。结合区域地质特征,从各层段样品的投点位置来看,反映物源由稳定的克拉通内部物源(相当大陆块物源区)向岩屑再旋回造山带区(碰撞造山带)再向混合型再旋回造山带区一个演变的过程。早期北西向展布的囊谦褶皱带冲断自西南向北东逆冲,在断层的下盘发生挠曲凹陷,形成前陆盆地,揭示了沉积早期盆地北、西北部的构造活动性强烈,为 Eg² 沉积时期提供成熟度很低的碎屑物质,由 Eg¹ 至 Eg² 沉积阶段长石含量降低而岩屑含量递增,构造强度逐渐增强,冲积扇-河流相层序处于发育阶段,因此,沉积了一套巨厚层状的砾岩、砂砾岩。中期青藏北部、东部发育大规模的走滑拉分作用,使早期的前陆盆地演变为拉分盆地。在 Eg³ 层序发育时,囊谦盆地受东缘扎曲断裂、西侧江达断裂控制,随边界断裂主应力由挤压转为右旋走滑拉张,盆地面积逐渐增大,长石含量增高而岩屑含量

表 2 囊谦古近纪盆地细碎屑岩主量元素分析结果

ω_B/%

Table 2 Analytical results of major elements in fine-clastic rock of Nangqen paleogene basin

| 岩性 样号 | 岩屑长石砂岩 | | | 长石岩屑砂岩 | | | 砂岩 | | | | 均值 | PAAS |
|--|--------|--------|--------|--------|--------|--------|---------|-------|-------|-------|-------|-------|
| | ys009 | ys 010 | ys 018 | ys 022 | ys 034 | ys 043 | S1-8-1* | S2-4* | S8-1* | S9-2* | | |
| SiO ₂ | 61.68 | 71.37 | 78.71 | 79.72 | 62.11 | 53.98 | 69.01 | 50.03 | 51.60 | 59.02 | 63.72 | 62.40 |
| Al ₂ O ₃ | 7.26 | 4.59 | 5.32 | 6.02 | 5.07 | 7.57 | 10.73 | 5.79 | 9.01 | 5.15 | 6.65 | 18.88 |
| Fe ₂ O ₃ | 2.59 | 2.23 | 1.50 | 1.88 | 1.33 | 2.21 | 5.40 | 1.40 | 1.20 | 0.90 | 2.06 | 7.18 |
| MgO | 1.62 | 0.57 | 0.21 | 0.81 | 0.86 | 0.63 | 0.06 | 0.05 | 0.50 | 0.50 | 0.58 | 2.19 |
| CaO | 23.53 | 10.23 | 5.71 | 4.22 | 15.08 | 17.68 | 4.50 | 21.10 | 17.70 | 18.50 | 13.83 | 1.29 |
| Na ₂ O | 0.44 | 0.64 | 1.02 | 1.11 | 0.80 | 0.21 | 0.45 | 0.21 | 0.20 | 0.44 | 0.55 | 1.19 |
| K ₂ O | 1.25 | 0.72 | 1.76 | 0.98 | 1.13 | 1.52 | 1.29 | 1.13 | 1.29 | 1.09 | 1.22 | 3.68 |
| MnO | 0.04 | 0.09 | 0.05 | 0.07 | 0.07 | 0.06 | 0.06 | 0.05 | 0.06 | 0.04 | 0.06 | 0.11 |
| TiO ₂ | 0.37 | 0.26 | 0.28 | 0.36 | 0.37 | 0.41 | 0.20 | 0.10 | 0.15 | 0.07 | 0.26 | 0.99 |
| P ₂ O ₅ | 0.07 | 0.06 | 0.05 | 0.07 | 0.07 | 0.07 | 0.07 | 0.13 | 0.15 | 0.00 | 0.08 | 0.16 |
| FeO | 0.15 | 0.35 | 0.15 | 0.35 | 0.10 | 0.15 | 1.60 | 1.10 | 0.70 | 0.30 | 0.50 | |
| LOI | 1.05 | 9.15 | 5.29 | 4.67 | 13.02 | 15.54 | 5.00 | 4.09 | 6.00 | 3.10 | | |
| Total | 99.00 | 91.11 | 94.76 | 95.59 | 86.99 | 84.49 | 93.37 | 81.09 | 82.58 | 86.01 | | |
| K ₂ O/Al ₂ O ₃ | 0.17 | 0.16 | 0.33 | 0.16 | 0.22 | 0.20 | 0.12 | 0.20 | 0.14 | 0.21 | | |
| Al ₂ O ₃ /TiO ₂ | 19.62 | 17.65 | 19.00 | 16.72 | 13.70 | 18.46 | 53.65 | 57.90 | 60.07 | 73.57 | | |
| ICV | 1.25 | 1.31 | 1.34 | 1.38 | 1.45 | 0.78 | 0.56 | 0.41 | 0.43 | 0.86 | | |
| CIA | 72 | 61 | 50 | 56 | 57 | 76 | 79 | 75 | 81 | 66 | | |
| CIW | 83 | 69 | 61 | 62 | 66 | 92 | 88 | 89 | 93 | 78 | | |

样品由核工业北京地质研究院分析测试研究中心分析; * 据周江羽等(2007); Fe₂O₃ 为全铁; 化学蚀变指数 CIA = Al₂O₃ × 100 / (Al₂O₃ + CaO + Na₂O + K₂O) 减分成熟度指数 ICV = (Fe₂O₃ + CaO + Na₂O + K₂O + MgO + TiO₂) / Al₂O₃; 化学风化作用指标 CIW = Al₂O₃ × 100 / (Al₂O₃ + CaO + Na₂O), 式中的氧化物质量分数均换算为摩尔数。

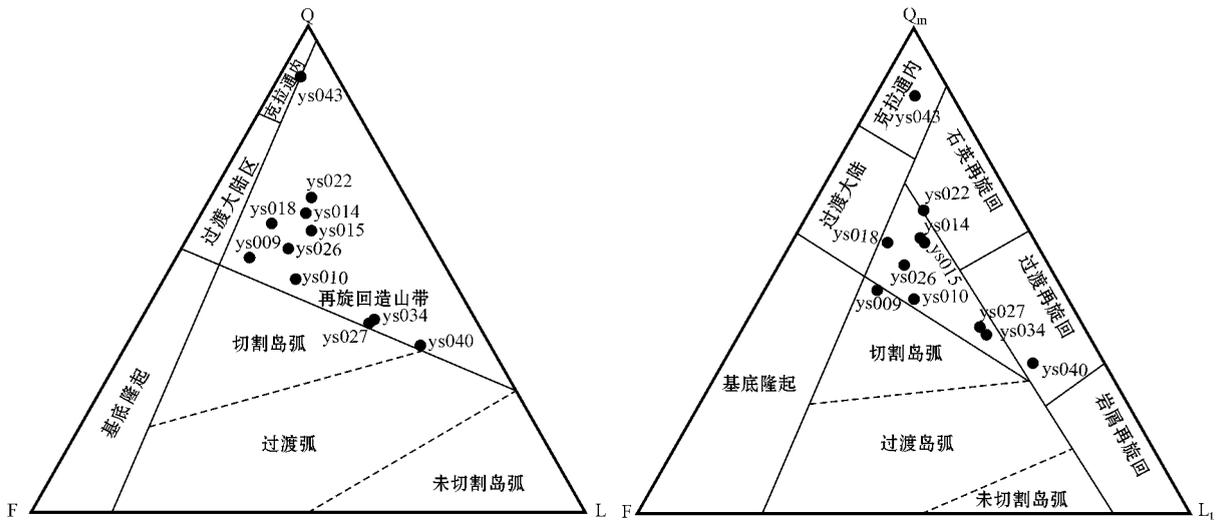


图 1 囊谦盆地贡觉组砂岩骨架成分和物源类型三角图(据 Dickinson and Suczek, 1979 ; Dickinson, 1983)

Fig. 1 Triangular diagram showing clastic components of Gonjo Formation sandstone and provenance types in Nangqen basin (after Dickinson and Suczek, 1979 ; Dickinson, 1983)

逐渐降低,构造运动逐渐减弱,但盆地西北、北部继续隆升遭受剥蚀,东部和南部则下降接受沉积,并伴有岩浆活动,湖泊层序发育阶段达到顶峰。晚期印度板块与欧亚板块碰撞进一步加剧,由走滑拉分的应力转变为走滑挤压应力,拉分盆地发育结束,形成晚期的褶皱冲断带及前陆盆地。随后进入混合型过渡型再旋回造山带区, Eg^4 、 Eg^5 层序构造运动逐渐减弱,长石含量先增加后降低而岩屑含量先降低后增加。综上所述,砂岩碎屑组分变化反映了盆地的逆冲挤压-拉分、走滑-挤压活动阶段,这种演变趋势可从各层序的碎屑组分变化得以体现。

4.2 砂岩常量元素与碎屑组分间的关系

K_2O/Al_2O_3 比值可区分细碎屑岩物源区岩石的矿物成分。Cox(1995)研究表明: K_2O/Al_2O_3 比值大于 0.5 时,母岩中具有相当多的碱性长石,若其比值小于 0.4 时,母岩中碱性长石含量较少。囊谦盆地贡觉组砂岩的 K_2O/Al_2O_3 比值范围介于 0.12~0.33,均小于 0.4,说明母岩中碱性长石的含量较低,与砂岩定量分析结果相吻合。

沉积物中 Al_2O_3/TiO_2 比值小于 14 时,沉积物的物质来源来自于铁镁质岩石;若其比值介于 19~28 范围内,物源为安山质和流纹质岩石(Roser and Korsch, 1986)。研究区 Eg^3 样品的 Al_2O_3/TiO_2 比值小于 14,沉积物物源中有少量的铁镁质岩石,可能由于横断山北段剪切-走滑断裂的活动,使得盆地基

底断裂下切至上地幔,诱发深部物质部分熔融,导致深部熔融体的喷发或侵入该层位。其他层位样品的 Al_2O_3/TiO_2 比值介于 17~20 之间,说明沉积物的物质来源主要为长英质岩石。

4.3 源区的古风化作用及对古气候的指示

Chittleborough(1991)认为相对稳定的元素氧化物(Al_2O_3 、 TiO_2)和不稳定的元素氧化物(Na_2O 、 CaO 、 MgO 、 K_2O)可用来估计各种各样的风化强度指标。化学蚀变作用指标 CIA 和化学风化作用指标 CIW 被广泛用于确定物源区风化特征(Nesbitt and Young, 1982; Harnois, 1988)。由于硅酸盐矿物中 CaO 与 Na_2O 通常以 1:1 的比例存在,所以 McLaren(1993)认为:当 CaO 的摩尔数大于 Na_2O 时, CaO 的摩尔数可以取 Na_2O 的摩尔数;而当 CaO 的摩尔数小于 Na_2O 时,则 CaO 的摩尔数就取 CaO 的摩尔数。由表 2 可知,碎屑岩的 CIA 指数由 Eg^1 层段至 Eg^4 下段逐渐降低(76~50),再向 Eg^4 上段逐渐增加(61~72)。 Eg^1 层段砂岩的 CIA 值最高,可能是由于处在稳定的构造背景,经过长距离的搬运而经受了较强的风化作用。化学风化作用指标 CIW 由 Eg^1 层段至 Eg^4 层段变化趋势与 CIA 指标一致。

碎屑岩的成分成熟度与沉积物形成的气候和构造背景相关,ICV 指数可以用来定量反映沉积物的成分成熟度,也可估计砂岩母岩组分。该区的碎屑岩 ICV 指数表明 Eg^1 至 Eg^4 层段的沉积物成分成

熟度由差变好再变差的趋势,反映了物源区的地质条件存在差异。碎屑岩 ICV 指数大于 1,常作为第一次旋回的沉积物在构造活动的地区沉积;ICV 指数小于 1,伴随着较强的风化作用,形成第一次旋回陆源沉积物(Cox, 1995)。研究区碎屑岩 ICV 指数 E_{g^1} 层段小于 1, E_{g^2} 至 E_{g^3} 层段均大于 1,且呈逐渐降低的趋势。

综上所述,囊谦盆地贡觉组自下而上处于一个温暖潮湿→干旱、炎热→潮湿的气候环境,贡觉组碎屑岩所受的风化作用强度自下而上为强→弱→强;成分成熟度具由差变好再变差的趋势。

5 结论

(1) 根据宏观与显微结构的总体特征以及砂岩碎屑成分定量分析,贡觉组自下而上砂岩类型为: E_{g^1} 段为长石岩屑砂岩; E_{g^2} 段为长石石英砂岩、岩屑砂岩; E_{g^3} 段为岩长石岩屑砂岩; E_{g^4} 段、 E_{g^5} 段为岩屑长石砂岩。

(2) 囊谦盆地贡觉组碎屑岩的化学蚀变指标(CIA)与化学风化作用指标(CIW),由 E_{g^1} 段至 E_{g^4} 段变化趋势一致,即砂岩所受的风化作用强度为强→弱→强;依据石英与长石和岩屑之和的比值以及化学组分变化指标(ICV)在垂向上的变化,由 E_{g^1} 段至 E_{g^4} 段的沉积物成分成熟度具由差变好再变差的趋势;沉积时期自下而上处于温暖潮湿→干旱、炎热→潮湿的气候环境。

(3) 依据 Dickinson 提出的 QFL 和 Q_mFL_t 图解,结合构造背景和盆地的演化,可判别贡觉组砂岩物源具由稳定克拉通内部物源向岩屑再旋回造山带区、再向混合型再旋回造山带区一个演变的过程。

(4) 囊谦盆地贡觉组砂岩的物源以长英质岩石为主,另外, E_{g^3} 层段物源有少量的铁镁质岩石,可能是由于横断山北段剪切-走滑断裂的活动使得盆地基底断裂下切至上地幔,诱发深部物质部分熔融,喷发或侵入该层位所致。

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